How to Solve the Rubik's Cube

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So you have a Rubik's Cube, and you've played with it and stared at it and taken it apart...need I go on any further? The following are two complete, fool-proof solutions to solving the cube from absolutely ***any*** *legal position. Credit goes not to me, but to David Singmaster, who wrote a book in 1980,* Notes on Rubik's Magic Cube*, which explains pretty much all of what you need to know, plus more. Singmaster wrote about all of these moves except the move for Step 2, which I discovered independently (along with many other people, no doubt).*

I've updated this page to include a second solution to the cube. I learned this solution from the Handbook of Cubik Math *by Alexander H. Frey, Jr. and David Singmaster. I would strongly recommend getting this book; there are all sorts of interesting problems and exercises to do. This solution is a bit more free-form than the first solution, as there are less moves to memorize. However, it probably requires a little more intuition about cubing on your part to be able to use it effectively. I'm not really sure which of the two solutions would be better to learn first. I prefer the second method, because it is definitely simpler.*

I should point out that these are both beginner-level solutions. They are easy to learn (in particular Solution #2). If you want to be able to solve the cube in 20 seconds, this is not the page for you: check out the speed cubing links later on in the page. The faster solutions generally require considerably more memorization and practice. If this is your first time solving the cube, I think you've come to the right place.

I have a couple of "cheat sheets" (Solution #1, Solution #2), which are one page documents, suitable for printing, that contain the moves. These are not suitable for learning with, rather they can be used as a quick reminder while you are trying to memorize the moves. They should print on one page in most browsers at normal text settings. If they don't fit, just reduce the size of the text in the browser and try again. These are new as of December 2003 so I am soliciting feedback (rubiks [at] jeays [dot] net)

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Solution #1

Step 0 -- Notation

Before we get started, we must work out a method for describing the various moves that will be made. There are six faces, with the following notations:

- Upper, or top face = U
- Down, or bottom face = D
- Left face = L
- Right face = R

- Front face = F
- Back face = B

We can turn each face either clockwise or counter-clockwise, with respect to the center (i.e. a move that may be clockwise to you, when looking at the cube, may not be clockwise for that face, in relation to the middle of the cube). The names for the different kind of moves (I'll use the U face as an example) are:

- A 90-degree turn clockwise on a face is denoted by U.
- A 90-degree turn counter-clockwise on a face is denoted by U' ("U prime") (Also note this is the same as U, done three times).
- A 180-degree turn either clockwise or counter-clockwise on a face, is denoted by U^2 ("U squared") and is the same as two clockwise turns, or two counter-clockwise turns.

We can refer to individual pieces by a two-letter (for edges) or three-letter (for corners) combination. For example, the piece in the upper right front corner is called URF, and the edge piece to the down and left of the cube is called DL. Also, these notations refer to the piece that is in that place at that time, **not** the piece that should go there.

Clockwise and counter-clockwise are also used to describe orientations of corner pieces. For the URF piece, for example, rotating it clockwise would result in the U side of the piece on the R face, the R side on the F face, and the F side on the U face. Similarly, for a counter-clockwise rotation, the U side of the piece would end up on the F face, the F side on the R face and the R side on the U face.

Also, note that during any sequence of moves the position of the center pieces with respect to one another is unchanged.

Step 1 -- Do the first face

I was thinking of omitting this step; if you've come so far as to seek help for doing the Rubik's cube, then you've probably been able to do one side. But I've included the details in for completeness.

The first step involves choosing a color, and getting all the pieces of that color to form a complete face. These must also be in the correct relative location.

First, we will do the edges. Let's say we pick white as the side to complete first (many people choose white as it is the easiest color to pick out). Turn the cube so that the white center piece is on the U face. Note that the centers are attached, so that they are always in the same position with respect to one another, unlike a cube of even degree (i.e. 2 x 2 x 2 or 4 x 4 x 4).

First, we put the edge pieces (those with 2 colors) in the right place. There are several possibilities. Note that when moving pieces around you should have the piece that you are working on the F face.

- White/Other color (OC) piece is on the D face. Rotate the D face so that it is directly underneath the place where it needs to go (on the U face). If the white side of the piece is on the D face, apply F^2, and it will be correct. If the white side of the piece is not on the D face, apply D R F' R'.
- White/OC piece is on the center slice (i.e. middle portion of the cube) . Apply F or F' to get the piece on the D face, and then perform above moves.

- White/OC piece is in correct position, but incorrectly rotated. Apply F^2 and do the above moves as necessary.

Second, we do the corners. There are six main possibilities for each of the four corner pieces:

- Corner piece in correct place. Do nothing.
- Corner piece is in the correct place, but incorrectly rotated, so that the piece needs rotating clockwise. Hold the cube so that this piece is in the URF location, and apply F D F' D' F D F'.
- Corner piece is in the correct place, but incorrectly rotated, so that the piece needs rotating counter-clockwise. Hold the cube so that this piece is in the URF location, and apply R' D' R D R' D' R.
- Corner piece on D face. Rotate D face so that the corner piece you want to move into position is directly underneath its intended location. If the corner piece has white (or whatever color you chose) on the bottom, and the destination of the piece is URF (i.e. the upper right hand corner on the front of the cube), apply R' D^2 R D R' D' R.
- Corner piece on D face, and white side of the corner is on the left hand side, assuming that the piece is going to the URF location. Apply F D F'.
- Corner piece on D face, and white side of the corner is on the right hand side, assuming that the piece is going to the URF location. Apply R' D' R.

You should be finished the white face by now. This step is fairly intuitive, so it shouldn't have been too much of a problem.

Step 2 -- Do the middle layer edge pieces

Okay, so the U face is done...Now we have to get the edge pieces of the middle layer in place, that is the FR, FL, BR, BL pieces.

There are four possibilities:

- Edge piece is in the correct place and oriented correctly -- do nothing.
- Edge piece is in correct place, but oriented incorrectly. In this case, you have to replace it with another piece temporarily. Choose an edge piece that is on the D face, and move it to the position of the aforementioned edge piece using the move described in the following list item.
- Edge piece is in an incorrect place in the middle layer. In most cases, you can just skip this edge piece for now, as it will move to the D face when you put the correct edge piece in that place. If you have two edge pieces in the middle layer that are in each other's correct places, then you will need to break the cycle by replacing one of those edge pieces with one of the D face edge pieces.
- Edge piece is on the D face. This is good. Let's say you want to move the yellow-red edge piece into place on the middle layer. (Your cube may not have yellow and red as adjacent pieces, so you may have to substitute different colors). Check which side of the yellow-red piece is actually on the D face. Say yellow is on the D face. Rotate the D face so that the yellow-red piece is opposite from the yellow center. (If the yellow center is on the F face, then the yellow-red piece is the DB piece, got it?). Now, hold the cube so that white is the U face, and the yellow center is on the F face. Which side of the yellow-red piece is the red face on? If the red center is on the L face, then apply F' D' F D L D L'. If the red center is on the R face, then apply F D F' D' R' D' R. One way to think about this move, if you're trying to memorize it, is that you are removing the corner piece on the U side right above the edge piece you're trying to replace, and then putting it back in from the other direction, with the side effect of

moving the edge piece into the correct place.

This will have to be repeated at least 4 times in order to get all of the 4 middle layer edge pieces into place.

Step 3 -- Form cross on last layer

The first two layers should now be completely correct. From now on, turn the cube upside-down, so that the first face (white, in my example) is the D face. It will remain this way until the cube is complete. The reason for this is just to make the manipulations a bit easier to perform.

On my cube, green is opposite to white, so I will refer to the green face as being the new U face for our purposes. We must now try to form a green cross, out of the green center, and the four edge pieces that surround it.

There are 4 possibilities:

- All four pieces are correct, and you have green cross on the U face. Do nothing.
- Two adjacent edge pieces are correct. For example, the UF and UR piece have green on the top, forming a sort of L shape, with the center. The UL and UB pieces do not have green on the top. In this situation, hold the cube so that the UF and UR pieces have green on the top (as in the example earlier in this paragraph), and apply B U L U' L' B'.
- Two opposite edge pieces are correct, and the other two aren't. Let's say UR and UL are correct (this should make a green line down the middle of the U face). Apply B L U L' U' B'.
- No edge pieces have green on the top. Hold the cube any way (still keeping the green center on the top) and apply B L U L' U' B' F U R U' R' F' (for those of you who want to memorize the moves, you should realize that this is the same as doing the move in the third part of this section, then rotating the cube 180 degrees, and then applying the move in the second part of this section).

You should now have the bottom two layers all correct, as before, and a green cross (or whatever the color on your cube whose center is opposite to white is) on the top face.

IMPORTANT: If the bottom two faces are perfectly correct, and you have 1 or 3 edge pieces that show green on the top, then your cube is messed up. Somebody (maybe you!) took it apart (or changed the stickers around) at some point in time. Might as well take it all apart right now, reassemble it correctly and start again.

Step 4 -- Rotate U face edge pieces

You now have a green cross on the U face, but...these edge pieces may not be in the correct order. This step involves rotating them so that the can be lined up with their respective colors.

- If all 4 pieces are correct (the entire cube is correct except for four corner pieces on the top layer), then do nothing.
- If 1 piece is correct, then rotate the whole cube so that this piece is in the UL position (make sure green is still on the top). If the remaining 3 edge pieces need to be rotated clockwise, apply R^2 D' U^2 R' L F^2 R L' D R^2. If the pieces need to be rotated counter-clockwise, apply R^2 D' R' L F^2 R L' U^2 D R^2.

- If 2 "adjacent" edge pieces (by "adjacent" here I mean pairs such as UF and UL, or UB and UL, and not UF and UB, or UR and UL), then rotate the U face so that only 1 edge piece is correct, and follow that rule.
- If 2 opposite (i.e. not adjacent!) edge pieces are correct, then apply U or U' and follow the rule for 0 edge pieces correct.
- If 0 edge pieces are correct, turn the U face so that: for the UF piece (which can be any piece), the F side of that piece is the same color as the R face center. Now apply R^2 D^2 B^2 D L^2 F^2 L^2 F^2 L^2 F^2 D' B^2 D^2 R^2.

The four U face edge pieces should now be in the correct place. The cube should be all correct now except for the four corner pieces on the U face.

Step 5 -- Position U face corner pieces

Now we must move the corner pieces into the right places.

There are 3 possibilities:

- All 4 corner pieces are in the right place, although not necessarily rotated correctly. Do nothing.
- 1 corner piece is in the right place. Hold the cube so that it is in the UFR position. If the remaining three corner pieces need to be rotated clockwise, apply L' U R U' L U R' U'. If they need to be rotated counter-clockwise, apply U R U' L' U R' U' L.
- 0 corner pieces are in the right place. If they all need to go to opposite corners, apply R' B^2 F R F' R' F R F' R' F R F' R' B^2 R. If they need to go to adjacent corners, hold the cube so that UFR and UFL pieces need swapping, and so do the UBR and UBL pieces. Apply B L U L' U' L U L' U' L U L' U' B'.

Okay, now all of the corner pieces should be in the right place. We're almost there!

Step 6 -- Rotate corner pieces

Hold the cube so that an incorrectly rotated corner piece is in the UFR position. If it needs to be rotated clockwise, apply F D F' D' F D F' D'. If it needs to be rotated counter-clockwise, apply D F D' F' D F D' F'. Now (and this is *extremely* important) turn the U face only, so that the next incorrectly rotated corner piece is in the UFR position. Apply one of the above moves, depending on which way it needs rotating. Repeat if more than two corner pieces are incorrectly rotated. After all pieces are rotated, simply turn the U face and complete the cube.

This step may be confusing, simply because after just one corner piece is rotated the cube is in quite serious disarray. Just make certain that you move only the U face and it should work out fine. I'll give one example to show exactly what will happen, for a simple example: the UFR piece needs rotating clockwise, and the UBR piece needs rotating counter-clockwise. Do these moves and the cube will be complete F D F' D' F D F' D' U D F D' F' D F D' F' U'.

Note that there are only certain combinations of incorrectly rotated pieces. If your cube gets to a position where there is a situation other than one of these, then it has probably been taken apart by small green aliens, so I would recommend disassembling it and starting over.

- One piece needs rotating clockwise, one piece needs rotating counter-clockwise, other two are correct.
- Three pieces all need rotating clockwise, other one is correct.
- Three pieces all need rotating counter-clockwise, other one is correct.
- Two pieces need rotating clockwise, two pieces need rotating counter-clockwise.
- I was going to write "all corner pieces are correct" here, but I guess that would be obvious.

Solution #2

Background for Solution #2

*If you are not familiar with the standard notation, please check Step 0 -- Notation from Solution #1. The following solution is a much easier to memorize way of solving the cube. Most of the moves are easy to understand, such that you don't even feel that you are memorizing anything. I will try to explain what to **think** when you are solving the cube.*

This is new as of December 2006. A lot of people have asked for pictures or videos explaining the moves, so I've joined the crowd at YouTube with some tutorial videos on cubing. I hope they are useful. Check out my How to Solve the Rubik's Cube Playlist on YouTube. Note that this explains Solution #2 only.

Step 1 -- U face edge pieces

So your cube is scrambled right now. The first thing to do is to chose a color, say white (it tends to stand out from the other colors on the cube). It's also a very good idea to always to a specific color first, since you will begin to learn which colors are adjacent, which speeds up things considerably.

The first step is to form a cross on the top face of the cube. Orient the cube so that the white center piece is on top. You want to get the correct pieces in the UL, UB, UR and UF locations. So, you will need to done some of the following moves: (be sure to do those in the first step first.

- If a white-other color (OC) piece is on the U face:
  - If white is in the U position, simply rotate the U face until the OC is lined up with its center.
  - If OC is in the U position, rotate the U face so that the piece is at an adjacent edge location to its desired location. Hold your cube so that white is the U center and OC is the F center. Now rotate U so that the white-OC piece is in the UR position. Now apply R' F'.
- If a white-OC piece is in the middle slice of the cube (the middle third), then hold the cube so that white is still on the U face, but this white-OC piece is in the FR location. Now, you should notice that you will be able to move it to the U face by applying F' (if the white face on the R side) or R (if the white face is on the F side). Find the spot where that white-OC piece should go. Rotate U until you can apply either F' or R to move the white-OC piece in the correct spot, so that the white face will move to the top. Examples: You want to move the piece in FR, with white being the R face, to its home location at UL, so apply U' F' U. You want to move FR, with white being the F face, to its home location at UL, so apply U^2 R U^2. See how you simply move U, then bring the edge piece up to the U face, then move U back to restore the original position, plus the piece you just moved.
- If a white-OC piece is on the bottom slice of the cube:

- If the white is on the D face, simply rotate D until the OC is directly underneath its center, and apply F^2 (assuming the piece is at the FD position) to put it in the correct location.
- If the OC is on the D face, hold the cube so white is the U center, and OC is the F center. Rotate D so that the white-OC piece is in the RD position, and apply R F' R' (you do not need R' if the UR piece had not been placed correctly yet).

You should now have a white cross formed on the top of your cube. Also you should be developing an intuition about these moves. What you will learn to do after a few times through this, is just think how the edge pieces are located *relative* to one another. This should speed things up.

Step 2 -- U face corner pieces

The second step is to correctly position **three** of the U face corner pieces. The reason that you will only put three of them and not four into place is that this method uses a "working space" which greatly simplifies the later steps.

There are three basic possibilities for putting corner pieces into place:

- The piece is on the D slice, with the white side *not* on the D side. In this case, rotate the D face so that it is directly underneath the location that it should go to. Now, hold the cube so that the piece is in the DRF spot, and the intended location is the UFR spot.
  - If white is on the R side of the corner piece in DRF, apply R' D' R.
  - If white is on the F side of the corner piece in DRF, apply F D F'.
- The corner piece is on the D slice, but the white face is on the D side. Rotate the D face so that the corner piece is in the DRF spot, and the intended location is the URF spot. Now apply R' D^2 R D R' D' R. Note that you are doing R' D^2 R to move the white side off the bottom of the cube, so that you can use one of the moves in the previous section. Also note that equivalent to this is: F D^2 F' D' F D F'. I would imagine if you are left-handed this would make things easier. Speaking of which, if you are left-handed, I would be interested if you naturally use a particular one of these processes. Personally I am right-handed and do the "R' D^2 R..." move, without really thinking about it.
- The corner piece in question is in the right spot but incorrectly rotated. Therefore, we must rotate it. Hold the cube so that it is in the URF location. Now,
  - If the white side is on the R face, apply R' D' R D R' D' R.
  - If the white side is on the F face, apply F D F' D' F D F'.

So now you should be done one side, except for one corner piece. This location will be used to swap corner pieces in and out, greatly simplifying later processes. The moves in the first two steps are really quite intuitive. After only a few repetitions, you should find them simple and natural to do.

Step 3 -- Middle edge pieces

This step involves correctly placing three of the four edge pieces on the "middle" layer of the cube. For these moves you will need to hold your cube so that the white face is on the bottom. The only middle layer edge piece that you do not position is the one right above the corner piece that you did not position correctly in step 2.

First of all, make sure the white side is on the bottom, and the "empty" (i.e. incorrect) corner piece on the white side is in the DRF location. The middle layer edge pieces will all be positioned in this step, except for the FR one.

To move a piece into position, rotate the cube about its vertical axis, so that the intended location is the FR location. (For example, you want to put the FL piece in place. Rotate the cube a quarter turn counter-clockwise). Now rotate the bottom slice so that the incorrect corner piece is in the DRF location. (So in the previous example -- for the FL piece -- you would first turn the cube, then apply D').

Now you are ready to do the move. The move to put the new edge piece into place can only be done if it is on the U slice. If it is, note which side is NOT on the U face. You will need to apply either F' or R, depending on the orientation of the edge piece you want to move. Then, apply U until the piece you want to move is in the UF or UR (depending on your previous move) location, and then F or R', to get it back to normal. I'd better give an example... Yellow is the F center. Orange is the R center. You wish to position the Yellow-Orange edge piece, to the FR position. You have already rotated the D face so that the DRF location does not contain a white corner piece. You see the Yellow-Orange piece in the UB location. You note that Orange is the U side, and Yellow is the B side. Thus, you apply F' U^2 F. All that description for three easy moves :-).

To continue, simply keep rotating D or D' and moving the cube to set up the same position, with an "empty" corner in DRF, the intended location at RF, and the piece you want to move in the U slice. Note that in some cases the piece may already be in the correct location, but orientated incorrectly. In this case you will have to take it out first (i.e. put any edge piece with the color whose center is opposite white on your cube into that location) and then put it back in that spot. In other words, with the DRF corner "empty" and the offending piece in the FR spot, apply F' U' F U R U' R'.

Now you should be done 2/3 of the cube, less two pieces: a middle layer edge piece and its adjacent corner piece, that appears to take a chunk out of the bottom (white) layer. Note that it is possible for the "empty" corner piece on the bottom layer to get solved by accident. If so, just ignore it, and pretend that it is unsolved.

Step 4 -- Solve remaining edge pieces

This is the only step that requires any actual memorization. I think you'll find that the moves from the other steps become very natural after a short time. There are two basic parts to this step, as follows. The goal of the whole step is to solve all of the 5 remaining edge pieces. The first part is to solve three of these (UF, UL, UB), and the second part is to solve the other two together.

First of all, hold the cube so that the "empty" edge piece is in the BR position, and thus the "empty" corner piece is in the RDB position. To do moves in this part, you first of all move a piece into the BR location, then move it to the U face, to one of those UF, UL, or UB positions. The move is as follows. First, optionally rotate U so that either the UR or UB location is lined up next to the BR location correctly. Then, apply R' or B such that after you do the move, the U face color of that BR edge piece moves to the U face. Then rotate U so that the edge piece you were moving is in the correct location. Then do R or B' (to undo the first part of this move). Pretty simple huh?! An example may be in order. Let's say the Blue-Yellow piece is in the BR location. Furthermore, Blue is the U color, and Yellow is the L color. You would thus apply U [to put the UL location (the destination) in the right spot] B U' B'. However, when actually trying to solve the cube quickly, before applying U' in the previous move, you should look to find the next edge piece that you wish to put in the right location. So rotate U until it is in the UB location, and then by applying B' you return the cube to a stable

position. Then, you will need to rotate U some amount to get the UL piece (Blue-Yellow in the example) back to the right place. There is a tremendous amount of freedom in this sequence of moves. In fact, you do not need to return the edge pieces to the correct spots in between repetitions of this move. Simply recognize how the pieces go with respect to one another, and then finally align them, when all three (UF, UL, UB) are done.

Also, note that sometimes the BR piece is not one of the U face pieces. In this case, you will have to put it where the edge piece that has the U and R face colors is, and bring the remaining U face edge piece that you need to solve into the BR location.

Now, there are four possibilities. The remaining edge pieces are the BR piece and the UR piece. Do the following:

- Luckily, the pieces are correct. Move to the next step and smile at your good fortune.
- The pieces are in the correct locations, but incorrectly oriented. Apply B U' B' U R' U R U'.
- Both edge pieces (BR and UR) have the same color on the R side of the piece, which is the same color as the R center. Apply U' R' U' R U' R' U' R U'.
- The other case (the UR piece has the R color on its U side, and B color on its R side, and the BR piece has the U color on its R side, and the R color on its B side). Apply B U B' U B U B' U^2.

If you want to reduce memorization at the expense of some speed, two of these moves suffice. In other words, if you apply all three of these moves in any sequence to an all-edges correct cube, you will get back an all-edges correct cube.

Step 5 -- Position corner pieces

In this step you want to move the remaining unsolved corner pieces to their correct locations, irrespective of orientation. Hold the cube so that the "empty" corner piece on the bottom (white) face is in the DRB location. Rotate the U face so that the piece that you want to position is in the UFL location. Apply L D^2 L'. Now, rotate the U face so that the location (with respect to the top-layer edge pieces) of the corner piece you are working on is in the UFL location. Now apply L D^2 L' again. Rotate U so that everything lines up. Repeat this (up to 3 times) until all of the corner pieces are in the right location.

This step is a little confusing at first. First of all, make sure your DRB piece is that "empty" (unsolved...not missing :-)) corner piece. Say the UFL piece is Blue-Yellow-Orange. But that piece should go in the URB location. You would do the following moves: L D^2 L' [move the piece in question out of the way (to the DRB location, if you're interested)] U' [move the correct **location** to the UFL spot] L D^2 L' [move the piece question back to the U slice] U [undo the U twist you did earlier]. One thing to note when doing this move, make sure the original UFL piece does not contain the color of the bottom face (white in my ongoing example). Also note that you are free to rotate the U face before the move so that you can move a particular corner piece that you want to position into the UFL location so that you can work with it. The only (slight) difference will be that you will need to rotate U at the end to make up for that. Note that these U-rotations should be very obvious. You can simply line up the top-layer edge pieces with their respective centers.

One other thing to note for this step is that after finishing this step, the DBR piece may still require rotating. This is different from Solution #1 if you are familiar with that. This will be handled in Step 6.

The remaining paragraphs in this section are optional, and a bit more advanced and lengthy, so you may want

to skip over them if this is your first time through. If you want to add a bit of speed to this solution and perhaps save some work during Step 6, read on. There are two ways of optimizing this step. First, you can position two of the corner pieces at once (instead of one, as I describe above), and second, you can often rotate some of the pieces appropriately while you are positioning them.

If you consider a plane of symmetry running through the four corners (yes, only three are actually needed) UFL, UBR, DFL, DBR, you will notice that L D^2 L' (the move I introduced at the start of this section) and F' D^2 F are mirror images. This means it's possible to do either one (the same move must be done twice, you can't mix and match) in order to complete this section. If you know how the pieces are going to rotate, then you can take advantage of this in order to do some orienting of the pieces while you position them.

I usually approach this section by first looking at the DBR piece. This allows you to position two pieces at once, since you don't just choose an arbitrary corner on the U face, you specifically rotate U so that when you start the move, you will send the DBR piece to the proper location. There are three possibilities for how it is rotated.

- If the U color is on the R face of the DBR piece, then doing the F' D^2 F move will correctly rotate it. So in this case, you would first of all position the U face so that the UFL position was where the DBR piece should go, then do F' D^2 F, then rotate U so to piece you just moved out of the UFL position will get moved into the correct place, and then do F' D^2 F again.
- If the U color is on the B face of the DBR piece, then doing the L D^2 L' move will correctly rotate it. Follow the same procedure as for the previous condition.
- If the U color is on the D face of the DBR piece, then you can't correctly rotate it with one of the moves. However, you can still correctly position two corner pieces, if the place that you are sending the DBR piece to is not occupied by a corner piece containing white, the D color.

If the DRB piece is already in the correct place, you can often save a rotation by choosing to correctly position a U face corner piece that has the U color on its U face. Both the F' D^2 F move or L D^2 L' move will rotate it correctly.

Step 6 -- Orient corner pieces correctly

Corner pieces must be rotated in pairs -- one clockwise and one counter-clockwise. Find two incorrectly rotated corner pieces that are on the same slice. Hold the cube so that one of the pieces in the UFL position and the other is somewhere on the U slice.

- To rotate a piece clockwise, apply L D^2 L' F' D^2 F.
- To rotate a piece counter-clockwise, apply F' D^2 F L D^2 L'.

After orienting the first corner piece, apply U until the other corner piece moves to the UFL location. You will then need to turn U to undo the previous twisting (this should be fairly obvious). Here's an explicit example -- the UFL piece needs rotating counter-clockwise, and the UFR piece needs rotating clockwise. The full sequence would be as follows: F' D^2 F L D^2 L' [orient UFL piece] U [position other corner] L D^2 L' F' D^2 F [orient original UFR piece] U' [undoes rotation of U that was done earlier].

You may need to apply this pattern up to 3 times, however if you use the strategy that I explain in Step 5 of

choosing between the two equivalent moves, you will normally need to do do this move 0 to 2 times. Note that you can only do one clockwise and one counter-clockwise twist. You cannot twist three corner pieces all clockwise, like the corner-twisting move in Solution #1. You always have to do them in pairs. Here's an example, let's say the UFL, UFR and UBR pieces all need rotating clockwise. The full sequence to rotate all three corners would be as follows: L D^2 L' F' D^2 F [orient UFL corner] U [move original UFR piece to working UFL corner] F' D^2 F L D^2 L' [turn original UFR counter-clockwise] F' D^2 F L D^2 L' [turn original UFR counter-clockwise again, solving it] U [move original UBR piece to working UFL corner] L D^2 L' F' D^2 F [orient original UBR corner] U^2 [realign U face].

If the two remaining corner pieces are diametrically opposed (e.g. at UFL and DRB), then you can apply R^2 (in this case) to bring both of them onto the U slice. Then, do the sequence. The apply R^2 again to get to the original configuration.

Frequently Asked Questions

How do I disassemble / assemble my cube?

So you want/need to take your cube apart. Turn a face 45 degrees. Obtain a fairly flat key or screwdriver. **Gently** lift the edge piece in the middle of the rotated face with your thumb, while **gently** inserting the screwdriver. **Slowly** prise the piece out. Do **not** force it. After one piece is out the rest come out fairly easily. You might want to take a good look at the mechanism that holds the cube together; it's quite interesting. If you were unclear before about how the centers always have the same relative position, it should be very clear now.

Time to put the cube back together? Assemble the first two layers correctly. This isn't too bad. Then for the top layer, first turn the center piece 45 degrees, then insert one edge piece, then the two surrounding corner pieces, then the adjacent edge pieces, so that one row is left without pieces. Then place the two corner pieces in their positions. For the final edge piece, hold it at about a 45 degree angle, and push it **gently** down into place.

Why must the cube be reassembled correctly?

Note that you must reassemble the cube so that it is solved correctly. If you reassemble the pieces haphazardly, there is but a 1 in 12 chance that your cube will be solvable. Wondering why? The following is not a rigorous proof but rather an explanation of what is happening. There are 12 edge pieces, and eight corner pieces in a cube. These move about separately, that is to say, an edge piece could never swap places with a corner piece. It's possible to move all but one of the edge pieces to any location, with either orientation. The last edge piece is forced to take on a particular orientation. You can see this for yourself by simply removing one edge piece and turning it around. If you now try to solve the cube, you will find that it is impossible. However, if you remove another (any other!) edge piece and flip this one too, and try to solve this cube, you will find that it is possible. Thus, there are two equally likely possibilities for the edge pieces when the cube is assembled randomly: edge pieces have been flipped from their true positions an even number of times, in which case the cube is solvable; or an odd number of times, in which case it's not.

Onto the corner pieces. Each corner piece has three possible orientations: correct, rotated clockwise, and rotated counter-clockwise. Of the 8 corner pieces, they must have a total number of rotations that is divisible

by three evenly. You can test this for yourself by twisting one corner piece, and trying to solve the cube. You'll find that it's impossible. If you twist another random piece the opposite way, these will cancel each other out and the cube will be solvable, however if it gets twisted the same way, the cube will still be unsolvable. You'll need a third twist in the same direction to return the cube to a solvable position. So, if all the corner pieces are in place, there are three equally likely situations to occur. Finally, we must look at the actual positions of the corner pieces, without regard to rotation. Notice how during step 5, it is never the case that only two corner pieces are out of position? Well, that is one of the unsolvable positions. The "first" six corner pieces can go anywhere. This leaves two corner pieces, for two corner spots. One of these positions is solvable, and one of them isn't.

The three events above are all independent, so applying a little probability, we can see that there are 2 x 3 x 2 = 12 "orbits" or groups of positions that cannot be reached from one another. Only one of these leads to the solved Rubik's Cube.

How many (legal) positions does the cube have?

The naive way to approach this problem is as follows: there are 12 edge pieces, and 8 corner pieces. First of all, note that (obviously) a corner piece could never go in the spot of an edge piece. Edge pieces and corner pieces can be arranged in 12! * 8! ways, according to basic counting laws. Now, each of the edge pieces can have one of two orientations, and each of the corner pieces can have one of three orientations. So we must multiply the previous number (counting the different locations of pieces), by $2^{12} * 3^8$, representing the total number of positions. This number is 519,024,039,293,878,272,000 ($\sim= 5.19 * 10^{20}$). However, this is not the correct answer, due to physical constraints of the cube. Not all of these positions are possible, as outlined in the previous section. We are able to rotate all but one of the corner pieces in any way, but the final corner piece is determined by the first seven. So we must divide our final answer by 3 (i.e. the number of orientations we originally gave to the final corner piece) to account for this. The same argument holds for the edge pieces, so we must also divide by 2. Finally, we cannot swap two edge pieces or two corner pieces. If you decide to take apart your cube, and simply swap two edge pieces, you will find the cube unsolvable. What will happen is that you can solve the edge pieces, but then two corner pieces will be swapped, and this situation cannot be fixed. So, we divide the total number again by 2 (i.e. we divide the above number by 2 * 3 * 2 = 12 -- "from" the previous section). This result, the "order" of the cube "group", is: 43,252,003,274,489,856,000 ($\sim= 4.32 * 10^{19}$). I like to give a physical representation to big numbers, so here goes: if you had a cube for every legal position, then you could cover the entire surface of the earth (including oceans :-)) about 250 times. A chain consisting of all the cube positions would stretch about 250 (coincidentally!) light years. Feel free to invent your own comparisons. Also, "order" and "group" have specific mathematical definitions which, alas, I still don't understand.

What are some records related to solving the Rubik's Cube?

The current official record for solving a Rubik's Cube is 10.48 seconds, achieved in 2006 by Toby Mao. In unofficial competition, or in practice, there are a number of people who have recorded faster times than these (see the Speed Cubing links below).

The original, oft-quoted world record that has been in the Guinness Book of World Records, is 22.95 seconds, set by Minh Thai, of Vietnam, in the original Rubik's Cube World Championship held in 1982.

Check RecordHolders.org for official records and Speedcubing.com for many unofficial records related to solving the Rubik's Cube.

Where do I purchase a Rubik's Cube?

When I originally wrote this page in 1995, finding a Rubik's Cube was often something of a challenge. However since then many reliable sources for Rubik's Cubes have sprung up. If you live in North America, your best bet is probably to visit the nearest Toys "R" Us. They normally have Rubik's Cubes in stock. I strongly recommend getting an official Rubik's Cube (branded with rubiks.com). There are some imitation cubes floating around and they tend to be of poor quality.

I bought an imitation Rubik's Cube from the "It Store" at the Rideau Center in Ottawa, Ontario, Canada (my hometown). The mechanism is a little stiff and the colors are glittery and non-standard (silver opposite gold, pink opposite red and blue opposite green). The manufacturer is Funworks and the Hologram Rubik's Cube cost is C$7.99. I wouldn't particularly recommend this brand but it would do in a pinch. As of August 2002 their site seems to have several annoying Javascript errors so it may be hard to find what you want. Also in Ottawa, Mrs. Tiggy Winkles has Rubik's products in stock.

I have been informed that Dollarama in Toronto sells imitation Rubik's Cubes for C$1.00. It's unlikely that the quality is very good but the price is certainly right. Another Toronto location with Rubik's Cubes is Toys Toys Toys in the Eaton Center. The cost is C$19.99 and it comes with a book. I have also been told that Cracker Barrel in the USA sells imitation Rubik's Cubes (called "Magic Cubes") for $4.99 US. The mechanism is a little stiff but solid.

There's a link to Amazon.com on the side here to an official Rubik's Cube. Full disclosure: I get a kickback of approximately 28 cents if you click on the link and buy through the site (there is no extra cost to you).

I'm bored, what do I do now?

Try the Rubik's Revenge, a 4 x 4 x 4 cube. I have written a partially complete solution to the Rubik's Revenge.

What are some links to other Rubik's Cube pages

These links were all verified December 29, 2006. This is not intended to be a definitive list of all cubing links, rather these have been selected because they are particularly interesting, useful, etc.

I. **Web Cubes**

- Michael Schubart's Rubik's Cube Java Applet (highly recommended, very easy to use and you can

see all six sides at once).
- Karl Hörnell has a beautiful Java cube (extremely realistic, a bit more difficult to manipulate quickly). I don't think words can quite describe how slick this looks.
- This Flash Animation from Eviltron is funny as well as practical. There's a little song and animation if you solve the cube. I did find the controls a little fussy, but you probably get used to it after a while. This is definitely worth checking out.
- Dan Knights wrote an online Java cube that is now being hosted by rubiks.com. It also allows you to solve arbitrary cube configurations (although it appears you have to pay for this feature) and demonstrate solutions. Highly recommended.
- Eric Dietz has written a Rubik's Cube Solver. You can enter the entire state of the cube and the program will list a sequence of moves to solve the cube, with available diagrams for each step. There is also C++ source code available if you are interested in programming.

II. General Cube Pages

- Georges Helm has an interesting Rubik's cube page with a lot of links and historical information.
- There is now an Official Rubik's Cube Site which is pretty slick, but there is not very much useful content, IMHO.
- Also try Matt Monroe's page, which has s instructions for solving the Rubik's Cube, among other things. He also has solutions for the Professor's Cube (5 x 5 x 5), Square 1 and Pyramix.
- Jin "Time Traveler" Kim has a Rubik's FAQ which covers a large number of Rubik's type puzzles. This page hasn't been updated in a long time but there is a lot of information you won't find anywhere else, particularly on other Rubik's Cube-like puzzles.
- Visit the The Domain of the Cube, an incredibly useful resource with lots of info and links.
- Martin Schöenert has an archive from the Cube-Lovers mailing list.
- Chris Loans has a Rubik's Cube page which also describes Solution #1.
- Check out the Wikipedia entry on the Rubik's Cube. You can even add or edit the article.
- Here's a no-notation solution from Chase Kimball and Matthew Campbell.
- Paolo Scalia has a website called Rubik's Illusions that explains both the layers method and the Petrus method, with animations.

III. Speed Cubing

- Visit the Speed Cubing site maintained by Ron van Bruchem. There are some really incredible records listed on this site.
- Chris Hardwick maintains his Rubik's Cube Page on the speedcubing.com site.
- The Rubik's Cube World Records Page only contains records achieved at competitions.
- The stiff_hands cube page has a lot of good speed cubing tips as well as a fast solution.
- Lars Petrus has written pages called Solving Rubik's Cube for Speed. The pages detail a highly optimized solution and the moves are demonstrated with Java cubes. Very neat.
- Jessica Fridrich, the second place finisher at the 2003 Championships, has a very interesting and informative Speed Cubing Page for those of you that want to improve your times.
- There's a Yahoo! Club devoted to speed cubing, Speed Solving Rubik's Cube which is quite active.

IV. Rubik's Cube Pages in Other Languages

- Danish (Dansk) (Word Document) (translation of this page)
- French (Français)
- German (Deutsch)
- Italian (Italiano)
- Japanese (日本語) (translation of this page)
- Portuguese (Português) (translation of this page)
- Spanish (Español)

V. **Mathematical / Technical Cube Pages**

- Professor W. D. Joyner has several excellent pages, particularly his Permutation Puzzles Page and his Lecture Notes on the Mathematics of the Rubik's Cube.
- David Miller has a fascinating page titled Solving Rubik's Cube Using the "Bestfast" Search Algorithm and "Profile" Tables. I would imagine this page would appeal to those with an interest in AI.
- Here are some extensive notes for a course called Mathematics of the Rubik's Cube at Stanford.

What are some games I can play with the cube?

An interesting game for two people is to get a correct cube, and for one person to secretly make a number of moves (try 4 to start with), and then the other person has to undo those moves. I've been able to do 7, maybe about 25% of the time. I can do 6 about 75% of the time, and 5 or less virtually always.

There are numerous patterns that can be made with a correct cube. Perhaps the two simplest are the "checkerboard" pattern, and the "dots" pattern, which are achieved by applying the following moves to a solved cube. For the checkerboard, do: R^2 L^2 U^2 D^2 F^2 B^2. For the dots pattern, do: R L' F B' U D' R L'. There are hundreds of other patterns to try -- The Domain of the Cube has a huge collection.

How do I orient the center pieces?

Some promotional or novelty cubes contain patterns on the stickers. Using the method above you can solve all of the cube as normal, except you may end up with the center pieces incorrectly oriented. If this is the case you can use a one or more of these three processes to correctly orient them.

- Rotate the U center 180 degrees: U R L U^2 R' L' U R L U^2 R' L'
- Rotate the U center clockwise 90 degrees and the F center anti-clockwise 90 degrees: F B' L R' U D' F' U' D L' R F' B U
- Rotate the U center clockwise 90 degrees and the D center anti-clockwise 90 degrees: R L' F^2 B^2 R L' U R L' F^2 B^2 R L' D'

How do I tell if the cube is unsolvable from a given state?

As mentioned above, if you disassemble the cube and reassemble it randomly, it is most likely that it will be impossible to solve. Try to solve the cube as normal. All of the first few steps should work. When you get

down to the final stage for edge pieces or corner pieces, and you notice one of the following oddities, you will need to disassemble the cube and reassemble it properly:

- One edge piece is flipped in place and all other edge pieces are correct.
- Two corner pieces need to be swapped and all other corner pieces are correct.
- One corner piece needs rotating and all other corner pieces are correct.

These are simplest cases. For the corner rotating one, if you count a correct piece as 0, a piece that needs rotating clockwise as -1 and a piece that needs rotating counter-clockwise as -1, then the sum of all corner pieces must be divisible by 3. Similar arguments can be established for the other two conditions.

How do I solve a Sudokube?

There appear to be a few Rubik's Cube-like puzzles shamelessly cashing in on the Sudoku craze. I have one such puzzle, which is simply a Rubik's Cube with each side labelled with the numbers 1 through 9. To solve the Sudokube, you have to get all numbers in order on each side, and all right-side-up (not a concern with the colors on a regular Rubik's Cube). There doesn't appear to be much in the way of actual Sudoku-playing in this puzzle, although, as with Sudoku, you do have to get one of each number in a 3 x 3 box.

It's actually a bit complicated, and a bit lame, in my humble opinion. I have one of these and the cube is of poor quality. The faces do not turn smoothly and there is a defect in the plastic in one of the corner pieces. Overall it feels kind of cheap, but it is functional. It's a bit bigger and it has lower density than a regular cube. I've included a link on the right here, however I do not have this exact model (same layout though). I bought mine at Chapters for $5 and it says "Distributed under license from Product Creations Limited, UK although I can't find it on their website.

That being said, the object is to put all of the numbers from 1 to 9 in order on each side of the cube. It's a bit more difficult than solving a regular Rubik's Cube, due to the following three basic observations:

- There is an orientation required for each of the center pieces, all labelled with a 5.
- There are two groups of ambiguous pieces: four 4/6 edge pieces and two 2/8 edge pieces. You don't know which of these pieces is which.
- There are two ambiguous pieces: 2/2 and 8/8, for which the correct orientation of these pieces is not clear.

Take a quick look at how the sudokube is set up before you scramble it. Note that the top layer (if you take the 5 with the Sudokube logo as the top) corner pieces all have 3/1 on two sides, and in the bottom layer they all have 7/9 on two sides. All the top layer edge pieces have a 2, and all the bottom layer edge pieces have an 8. Strangely, the 9s are underlined, presumably to distinguish them from the 6s, but it's not necessary because all of the 6s are on edge pieces and all of the 9s are on corner pieces.

I don't know what officially counts as "cheating" but if you are just trying to get it done, I would recommend putting a small bit of tape on the U and D sides of the 2/2, 8/8 and both 2/8 pieces, if you are starting with a

solved sudokube. This way you will know how these are oriented. Also, you will need a way of distinguishing between the 4/6 pieces. I put some tape on the 4 and 6 faces one one side of the cube (call it F) in a particular spot, then put some tape on the 4 and 6 faces on the opposite site (i.e. B) in a different spot. The 4 and 6 faces on the L and R sides (given that the U face is the side that has the 5 with the Sudokube logo) do not have any tape. If you do this, you can simply solve the cube as normal, and then just follow the instructions in How do I orient the center pieces? to finish the cube. You can start with the side that includes the 5 with *sudokube* text underneath it, to keep track of which side is which.

If you are given a sudokube in a scrambled state, you will have to engage in some trial and error (which is not in the spirit of the original puzzle, in my opinion). Try solving the cube as normal. You may come across a situation that seems impossible, for instance, a situation in which all of the edge pieces are solved, and all of the corners appear to be solved, except for two corners that need swapping locations. If this happens, then you have a couple of edge pieces swapped (although it's not possible to tell because the pieces look the same). If you are not using tape, you'll have to immediately swap the 2/8 pieces and try again, until you either solve the cube or reach some sort of impossible situation, upon which you will have to try another combination of some of the ambiguous pieces. If you are using tape, place some tape on of the pieces to remind you which orientation of those pieces you were using, and try again. This is definitely quite frustrating without tape.

Please let me know if you find a good straightforward solution that does not require tape or backtracking.

Here are some other possible misspellings, so people can find this page with a search engine: suduko cube, sudocube, sudoku kube, su doku, soduko, soduku, sodoku.

Miscellaneous

Personal Records

My best time for solving the Rubik's Cube is 40 seconds, set on February 21, 1998, using Solution #2. My record with Solution #1 is 57 seconds. I also keep a record for solving 5 straight cubes. My record, set on February 13, 1998 is 286 seconds (average of 57.2 seconds per cube).

On February 1, 1996 I managed to do the cube in only 6 "looks". I haven't really tried to break this record since then, it is too taxing on the mind and I don't have a photographic memory or anything like that. Here's where I took my "looks": one at the start, then I solved the edge pieces on the first face; one look to solve the corner pieces of that first face; two looks for the middle edge pieces; one look for Step 3 and one look for the last three steps (note that they Step 4 is totally independent from Steps 5 and 6, and it's possible to look ahead and see which corner pieces will need to be rotated in which directions).

Page History

A short note about the history of this page. The previous locations of this page were `http://qlink.queensu.ca/~4mj2/rubiks.html` (original) and `http://www.ncf.carleton.ca/~ad161/rubiks.html`. I hope that this current URL, `http://jeays.net/rubiks.htm` will be this page's permanent home. I created the page in November 1995 during a period of renewed interest in the cube for me. I did have a counter on my home page at that time, which was getting around 5 hits per day. I assumed that the traffic on the cube page would be a subset of that.

I was extremely surprised when I put a hit counter on the page in October 1997 to see that it was getting around 50 hits per day. This page underwent a major overhaul in December 1997 when I added the second solution. By the time that my university account expired in April 1999, the page was receiving around 120 hits per day.

By August 2002, this page, and its previous revisions had received somewhere on the order of 250,000 hits, about 120,000 of them on `http://jeays.net`, which I started in January 2001. In 2006 the page received approximately 750,000 views. Frankly, if someone told me that the page would get 1000 hits the night, in late 1995, after I wrote the initial version (probably while procrastinating over doing my homework), I don't think I would have believed them. Thanks for coming, and I hope you'll continue to use the page and recommend it to your friends that are interested in the cube.

Poll Archives

February 2005

I think the poll software had some serious glitches for this one. Some of the vote totals were going down from day to day. In any case, the question was 'How old were you when you first solved the cube?' and approximately 2/3 of respondents said 0-17, 1/5 said 18-29 and the remaining responses were distributed fairly evenly among the other age groups, 30-44, 45-64 and 65+. The final totals on the poll said over 90% were in the 0-17 category but I'm almost certain that this was due to a software flaw. I may re-run this poll one month when I get some better poll software. In any case, I can't say I'm overly surprised at the results since the cube came out in the early 80s, which means that everybody younger than about 40 probably had access to the cube in the 0-17 age range.

March 2005 - November 2005

I know, I was supposed to do a poll every month. I guess that didn't quite happen. The question was: ' How many people have you taught to do the cube?'. The final results for this poll over 16,000 votes were as follows: 60% said nobody, 11% said one person, 8% said 2-4 people, 6% said 5-9 people and 13% said 10 or more. I'm a little skeptical about the number of people teaching 10 or more, but it's always possible.

December 2005 - December 2006

There was a poll about how many cubes you have owned. I think the polling software is incredibly inaccurate, so this is the last poll for now. The results were probably something like this: 20% have never had a cube, 50% have had one, 35% have had 2-4, and the remaining 10% have had 5 or more.

Web Tools That Reference This Page

- Alexa: Overview, Write a Review, Traffic Detail
- Digg.com: diggs (bookmarks to this page)
- Google: pages that link here, similar pages
- Wayback Machine: Older versions of this page

Contact Me

Comments, Questions, Feedback, Concerns, Musings, Observations, New Moves, Record Times You'd Like to Share With Someone Who Might Care, Criticisms, Observations of Errors in the Text and Flames can all be directed to `rubiks [at] jeays [dot] net`, and I'll be happy to answer these. I do get some emails with generic complaints about the instructions, but I can't help you if you don't have a specific question. Tell me what you tried and what went wrong, and then I should be able to help you.

Try checking out my How to Solve the Rubik's Cube Playlist on YouTube if you want to see the moves for Solution #2 in action.

If you are down to the last few pieces and your cube is in a position for which there does not appear to be an appropriate move, you might want to check the list of unsolvable positions. Please note that I do not have any solutions to any other puzzles (other than the partial solution to the Rubik's Revenge).

N'hésitez pas à communiquer avec moi en français.

One more thing, I guess it's too bad that there isn't a "URL" piece...oh, forget it!

Last updated: December 6, 2006.

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